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How Energy Constraints Drive Firms' Participation in the Global Value Chain? International Evidence

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ABSTRACT

This study explores how energy constraints affect firms' participation in global value chains (GVCs). Drawing on extensive plant-level data from the World Bank Enterprise Survey, covering the manufacturing sector in 119 countries from 2005 to 2022, the analysis reveals that energy constraints significantly hinder firms' ability to engage in GVCs. This adverse effect is primarily driven by reduced productivity, increased energy expenses, and diminished investments in machinery. However, the impact is not uniform, varying by time periods, firm sizes, sectors, and regions. Smaller firms and those in energy-intensive industries are particularly vulnerable, while regional differences underscore the role of infrastructure quality and the effectiveness of energy policies. The robustness of the findings is verified using alternative measures and approaches that mitigate potential endogeneity concerns. These insights provide important policy implications aimed at enhancing firms' participation in GVCs through targeted energy infrastructure and policy improvements.

Keywords: Energy Constraint, Energy Poverty, Global Value Chain, Productivity, Technology
JEL Classifications: F14; F15; L25; O13

1. INTRODUCTION

Energy constraints and international trade are key factors influencing economic growth and development (Vernon, 2015; Cotter et al., 2021). The interaction between these factors has gained the interest of researchers and policymakers. Energy constraints, on one side, add production costs and limit product differentiation opportunities (Allcott et al., 2016), reducing the potential for market entry on a global scale (Tavassoli, 2018). Conversely, international trade can help mitigate energy shortages (Flores, 2007) and bolster energy security (Leal-Arcas, 2015). Recent studies have highlighted that energy cuts can diminish productivity (Cole et al., 2018; Grainger and Zhang, 2019) and prompt firms to transition away from energy-intensive technologies (Abeberese, 2017; Abeberese et al., 2021) in developing economies, impacting their integration into global value chains (GVC). Therefore, a comprehensive analysis of the relationship between energy constraints and firm participation in GVC is warranted.

Participation in GVC offers firms the opportunity to enhance technology, gain know-how, and establish trade connections (Gereffi, 2019). A growing body of research has examined the factors driving GVC participation and its implications for firm performance (Amador and Cabral, 2016; Criscuolo and Timmis, 2017). This research underscores the role of productivity and innovation, among other factors, as key determinants of firm GVC participation (Lu et al., 2018; Reddy et al., 2020). However, there has been limited focus on how energy constraints influence firms' participation in GVC. Addressing this gap, the aim of this study is to explore the impact of energy constraints on firms' GVC participation.

To achieve this aim, we leverage data from a comprehensive firm-level survey covering 119 countries between 2005 and 2022,

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sourced from the World Bank Enterprise Survey (WBES). We gauge energy constraints using firms' self-reported assessment of electricity obstacles (Churchill and Smyth, 2020; Asiedu et al., 2021) and supplement this with objective indicators such as the frequency of power outages and associated losses. Moreover, in line with Doan and Le (2022), we define GVC firms as those engaging in two-way trade and holding global quality certifications.

Our results reveal that energy constraints negatively influence GVC participation, mainly by decreasing productivity and encouraging a move towards technologies that use less electricity. Nonetheless, this impact is not uniform; it differs across various timeframes, firm sizes, industries, and geographic regions. This paper makes a unique contribution to the literature by being the first to provide cross-country, firm-level evidence on the impact of energy constraints on GVC participation using an extensive sample spanning 17 years. The study not only highlights the direct impact of energy shortages on firms' productivity and operational costs but also explores the mediating pathways through which energy constraints affect GVC participation, such as reduced capital investments and technology shifts. Furthermore, it offers a detailed analysis of how these effects vary by firm size, industry type, and geographic region, shedding light on the heterogeneous nature of the problem. By employing robust methodological approaches that address potential endogeneity issues, including entropy balancing and instrumental variable techniques, the research ensures the reliability of its findings and provides policymakers with actionable insights aimed at enhancing energy policy and GVC participation strategies.

The rest of the paper is structured as follows. Section 2 reviews relevant literature and discusses mechanisms. Section 3 gives a data description and specifies model. Section 4 provides the main empirical findings and investigates channels in which the effects of energy constraints on GVC participation are transferred. The final section concludes.

2. LITERATURE REVIEW

2.1. Theory of GVC Participation

The fragmentation theory and the new trade theory can be used to explain the firm's participation in GVC. The former theory is based on the position of various steps in the process of production to uncover the driving forces of GVC establishment, participation, and upgrading (Athukorala and Yamashita, 2006). In particular, the creation of GVCs occurs when there exists fragmentation of production processes into several stages and separation across nations. Such fragmentation happens when firms can (i) take advantages of cheaper labor and production costs when the fragmented production tasks are put in a new area, (ii) lower the related costs of connecting remote production tasks, and (iii) minimize the costs to form the GVC linkages. Alternatively, both fixed costs and the mean productivity degree of manufacturers play a decisive role in orienting the potential resources of the countries into GVC activities (Antras and Foley, 2015).

Meanwhile, the latter theory is based on firm heterogeneity to provide an alternative interpretation for the GVC decision-making of firms (Melitz, 2003; Antras and Helpman, 2004). Specifically, this theory contended that firm heterogeneity, such as efficacy as well as fixed and variable costs, spur firm into GVC. As involvement in global trade leads to greater trade costs, only firms with high efficiency can afford to pay such costs. The empirical studies indicated that two-way traders find it easier to cover sunk costs of international trade due to greater size, a better position to obtain economies of scale, and higher productivity (Antras et al., 2017).

These theories together explain the firm's decision to become manufacturers of final goods or multiple traders who provide immediate products in the GVC. On the one side, being the manufacturers of final goods, firms must be efficient enough to pay greater trade costs to involve in global trade via outsourcing many production stages worldwide. In the meantime, suppliers of immediate goods have to show their efficiency to be chosen for the GVC by cutting labor, production, and related trade costs. In this domain, GVC participation can be viewed as a strategic choice that is selected when firms reach the threshold of production efficiency. If efficiency is viewed as a competitive advantage in which a business employs a value-generating strategy (for example, cutting production costs and reducing prices) not done by other competitors at the same time, GVC participation could be led by firms' capabilities and resources (Barney, 2001). On the other side, once the "rules of the game" is formed, institutions can influence the productivity of firm operations (North, 1990). Strategic choices depend on sector customs, business abilities, and the formal and informal restrictions of a given institutional environment that firms' CEO suffer (Bruton et al., 2012). Thus, resource-based and institution-based theories are used to explain the determinants of GVC participation.

The literature on strategic management suggests three ways to rationalize firms' strategic behaviors, named the "strategy tripod" (Peng et al., 2009). In this view, the resource-based and institution-based view play as two pillars of such a strategy. Particularly, the former view stresses the function of resources and capabilities in enduring competitive advantages, therefore guaranteeing businesses' development and survival over time (Barney, 2001; Krammer et al., 2018). Similarly, the firm heterogeneity in terms of assets help explains the divergence of firm performance as well as the capabilities to conduct particular strategic activities (Barney, 2001). Meanwhile, the institution-based view emphasizes the nexus between institutions and organizations in shaping business decision-making. Moreover, while the resource-based view concentrates on the importance of internal factors, the institution-based view highlights the role of the institutional framework.

2.2. Energy Constraints

Energy plays a crucial role in addressing global development challenges. Specifically, access to electricity is closely associated with essential resources, food security, social services, education, income generation, and effective governance (Oparaocha and Dutta, 2011). The availability and utilization of electricity exhibit significant disparities among countries based on factors such as geography, level of development, cultural context, and even within countries, spanning from rural to urban areas.

Energy constraints have an impact on both household consumption and business activities. In developing countries, where electricity supply is unreliable, it has a negative effect on the production, investment, and growth of firms. Fluctuations and power outages can cause damage to equipment, halt production processes, and compromise the quality of products. The frequency and duration of electricity disruptions are crucial factors in evaluating the reliability of energy infrastructure, which is essential for sustainable socio-economic development. According to Mertzanis (2018), insufficient access to affordable energy sources hampers productive investments, limits employment opportunities, and leads to the use of fossil fuels and biomass, resulting in adverse effects on human health and the environment.

However, there is no broadly agreed upon definition of access to energy. The difficulties in reaching a consensus definition of access to energy arise because the relevant literature largely draws on the poverty literature. In the latter, poverty is generally linked to the inadequate levels of income and consumption to fulfil basic human needs. In this view, energy constraints imply an inadequate quantity of energy to meet essential consumption needs of households and firms. Such needs are typically estimated by engineering or normative processes, which are largely the domain of government authority. Thus, estimates of energy consumption needs may suffer from inherent subjectivity or institutional bias (i.e. political considerations). Moreover, given the varying dynamics of poverty level and composition within and across countries as a result of economic (i.e. income) and non-economic (i.e. demographics) factors, energy needs and constraints are themselves subject to recurrent revisions depending on geographical location, climatic conditions, resource endowments, etc. Based on these considerations, Pachauri (2011) argued that reaching a consensus definition of energy constraints presupposes agreement on three issues: the content and composition of basic energy needs; the thresholds defining evolving basic energy needs; and household and firm expenditure on energy by income class. Reaching an agreement on these issues is not an easy task; and this affects the development of appropriate energy policy. Further, defining energy constraints for firms would require a focus on the firms' needs and characteristics as well as the on their operating environment.

2.3. Effects of Energy Constraints on GVC Participation

Given the nature of the GVC participation literature, we bridge various papers associated with the strands of GVC and energy constraints. We start by investigating the role of energy constraints in forming firm decisions.

Confronting energy constraints, firms may react in several ways. If firms face planned energy shortages, they might decide to invest in improving energy efficiency. However, when electricity outages lessen capital productivity, capital investments might decrease (Abeberese et al., 2021). Another response is to purchase electricity generators which requires extra capital and diesel consumption, thereby lowering productivity due to the investment's crowding-out effect (Reinikka and Svensson, 2002). The cost of self-electricity supply may be too high for some firms, especially small and medium-sized firms, preventing them from switching their operations to those requiring vast consumption of electricity (Sik Lee et al., 1999). Also, a firm can choose to outsource the production of energy-intensive inputs, causing a reduction of labor, capital, and other energy sources in producing such inputs. These responses may reduce productivity.

The new-new trade theories contend that firm productivity drives export market participation (Melitz, 2003). Specifically, highly productive firms may self-choose to enter overseas markets as they own the required resources to surpass the sunk costs. A rich literature of empirical studies supports this prediction (Reddy et al., 2020; Reddy and Sasidharan, 2021; Gopalan et al., 2022).

Based on the above arguments, we propose the following hypothesis:

H_1: Energy constraints reduce firm productivity, thereby hindering firms from GVC participation.

Energy constraints, including limited availability and rising costs, increase operational expenses for firms, which subsequently diminishes their participation in GVC. The rising energy costs and limited availability of energy resources are critical issues for manufacturing firms, as highlighted by Mickovic and Wouters (2020), who emphasize that energy costs constitute a substantial portion of operational expenses. When energy becomes more expensive or less accessible, firms face increased costs, which erode profit margins and reduce competitiveness in GVCs. This is corroborated by Kumar et al. (2023), who found that factors such as raw material prices and operational inefficiencies significantly drive energy intensity in Indian manufacturing firms, necessitating effective policymaking to mitigate these impacts. Jones and Kierzkowski (2016) discuss how firms within GVCs compete on both cost and efficiency. High energy costs can place firms at a competitive disadvantage, making it difficult for them to compete with firms in regions where energy is more affordable. Baldwin and Lopez-Gonzalez (2015) emphasize the importance of cost-effective energy for attracting foreign direct investment in manufacturing sectors. High energy costs can deter such investments, as firms seek to optimize their production costs within GVCs. Gereffi and Fernandez-Stark (2011) point out that reliable energy supply is crucial for maintaining consistent production schedules and meeting the demands of GVCs. Energy constraints can lead to production disruptions, making firms less reliable as partners in these chains.

Based on the above viewpoints, we raise the following hypothesis:

H_2: Energy constraints raises energy costs, thereby diminishing firm participation in GVC.

If replacing intermediate goods is too expensive in the short run, firms may suffer performance reduction due to decreased output or additional costs due to the requirements to re-organize production plans (Fisher-Vanden et al., 2015). In this vein, lacking possible sources of electricity, firms must stop operation, generating wastes of non-flexible inputs like labor or some raw materials that might be damaged during power cuts (Allcott et al., 2016), or substitute away from electricity-intensive technology to less technologically advanced one (Abeberese et al., 2021). Abeberese (2017) stressed that Indian firms refuse to switch to productivity-improving sectors with a high degree of technological sophistication as they fear dependence on extremely priced electricity and change their production models toward less electricity-contingent technologies.

Scholars have investigated the role of innovation in shaping firms' trade behaviors. More the advantage of lower costs and more product differentiation allows innovative firms to enter the global markets (Tavassoli, 2018). Reddy et al. (2020) pointed out that firm innovation is a determinant of GVC participation as the innovative and technological ability helps a firm meet the rigorous global standards, which influences a firm's involvement in GVC. The study on Ghanaian manufacturing firms during an electricity rationing period revealed a decline in investment in plant and machinery, particularly in electricity-intensive sectors, highlighting how inadequate electricity provision can curb firm growth and investment (Abeberese, 2020). This reduction in investment can hinder firms' ability to participate effectively in GVCs, as they may lack the necessary infrastructure and capacity to meet global standards.

Based on the above discussions, we raise the following hypothesis:

H_3: Energy constraints make a firm purchase less electricity machine, thereby lowering firm participation in GVC.

3. METHODOLOGY

3.1. Variables

This paper uses cross-sectional data taken from the Enterprise Surveys of the World Bank.[1] We keep the data of manufacturing enterprises, as this sector works under the trade theory. To clean the data, we drop missing observations and winsorize all continuous variables at the 1st and 99th percentile levels of their distribution to reduce the problem of our results being potentially led by outliers. Specifically, we replace the values less than the 1st percentile with the value of the 1st percentile, and we do the same for the 99th percentile. The total number of observations is 54,249, covering 119 countries[2] from 2005 to 2022.

3.1.1. Dependent variable:

A growing literature has measured GVC participation. GVC participants enable firms to meet the requirement of global quality standards (Kergroach, 2019; Doan and Le, 2022). We follow Doan and Le (2022) to define GVC participants as international traders holding an international quality certification. They argued that such a certification help firms cut transaction costs due to the guarantee of information identification. For robustness check, we also use a wider measure for GVC firms that are both exporters and importers.

1. The data that support the findings of this study are available from the corresponding author upon reasonable request.
2. The list of countries is reported in Table A1 of the Appendix.

3.1.2. Independent variables: Energy constraints

We define a firm with energy constraints if the firm answers that electricity was an obstacle to its operation. This variable is obtained from the answer to the survey question: "To what degree is electricity an obstacle to the current operations to this establishment?" The five alternative answers are "no obstacle," "minor obstacle," "moderate obstacle," "major obstacle" and "very severe obstacle." To simplify the discussion, we re-classify the answers such that "no obstacle," "minor," and "moderate" are aligned with "no energy constraint," and "major" and "very severe obstacles" are aligned with "energy constraints" respectively. We create the independent variable EC that takes a value of 1 if a firm faces energy constraints and 0 otherwise. About 34% of the respondents suffer energy constraints.

It is important to stress that our measure of energy constraints is subjective and that such a measure of constraints has been used in various papers (Churchill and Smyth, 2020; Asiedu et al., 2021). One benefit of our energy constraint measure is that it captures a firm's perception of the degree to which electricity hinders their business operations. This is pivotal because a firm's perception is one of the most vital determinants that affect firms' decision-making of operation (Asiedu and Freeman, 2009). For robustness check, we also use the objective measure.

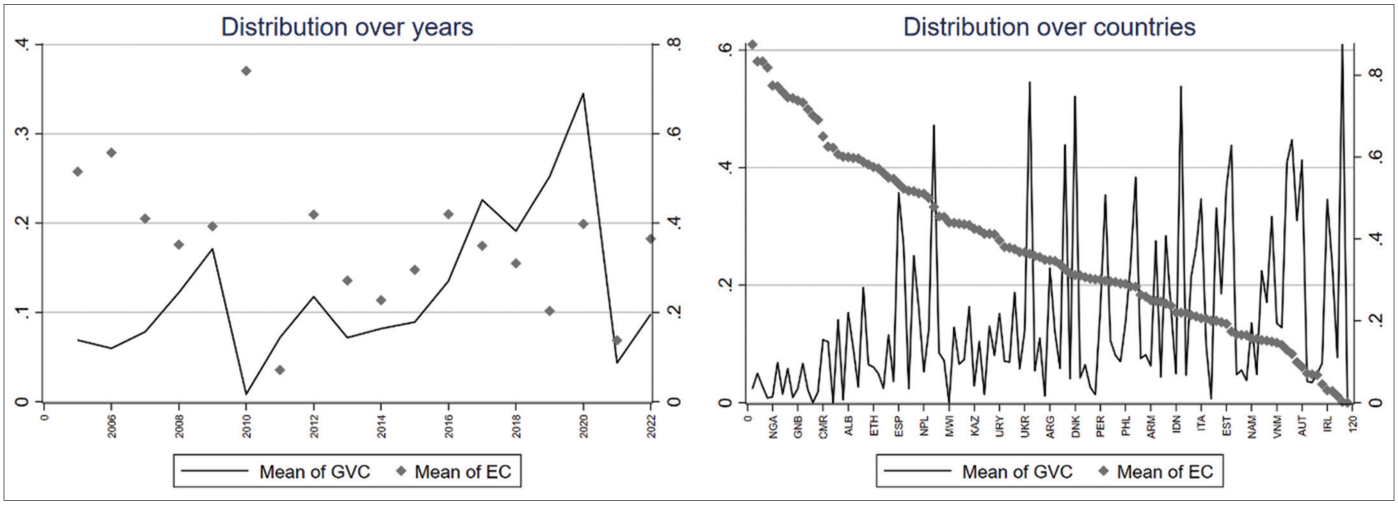
Figure 1 exhibits the means of GVC and Energy by years and countries. The left-hand side panel indicates that while GVC fluctuated around the mean between 2005 and 2015 and increased in the post-2015, Energy tends to decrease over the period. The right-hand side panel shows that the distribution of GVC and energy constraint varies considerably among countries.

3.1.3. Control variables

We build on the rich literature on the driving forces of firm participation in GVC (Reddy et al., 2020; Reddy and Sasidharan, 2021) in order to incorporate variables to monitor the influences on GVC participation. The variable Sale is the natural logarithm of the sales per worker. It is believed that firms with higher sales are more likely to participate in GVCs compared to firms with lower sales. We control firm age (*FirmAge*) as mature firms suffer less sunk cost compared with younger ones. Also, it is expected that managers' past experience (*FirmManager*) in the current sector is in a better position to deal with the issues of legal complications. Variable Informal takes a value of 1 if a firm started operating without formal registration and 0 otherwise. Firms that start operating in the informal sector but then switch to the formal one are less likely to involve in GVC than those that are established with registered firms (Colovic et al., 2022).

We also add variables to control the effects of innovation, digital transformation, and foreign connections on firm GVC. Variable innovation takes the value of 1 if a firm creates a new product or new process and 0 otherwise. This variable reflects the output innovation in which firms with more innovative ability are more likely to participate in GVC (Reddy et al., 2020). Variable *Digital* takes a value of one if a firm uses email to communicate with clients and suppliers, has a business website, or has an Internet connection (Gopalan et al., 2022). External network reflects the

Figure 1: Distribution of GVC participation (GVC) and energy constraints (EC) over time and sourcing countries



The mean value of GVC is on the left-right scale, and the mean value of energy constraints variable is on the right-hand scale

firm's trend toward the overseas market, consisting of foreign ownership (*Foreign*) or foreign technology (*Foreigntech*). These linkages are supposed to have a positive association with GVC participation (Reddy et al., 2020). As financial constraints hinder firms from participating in GVC (Reddy and Sasidharan, 2021), we use a measure of financial constraint to capture this effect. Following Doan and Le (2022), we construct a variable *FinObstacle* that takes a value of one if a firm faces major or very severe financial obstacles and zero otherwise.

Panel A of Table 1 shows that the average GVC participation rate of energy constraint firms is less than that of no energy constraint ones, and this difference is statistically significant at 1%. It can also be seen that the average GVC participation rate is higher in more productive, high machine purchase, high energy cost, and large-sized firms than their counterparts in Panel B, C, D, and E of Table 1, respectively[3]. We provide the statistical description of the variables in Table 2.

Table 1: Break-down of GVC participation by firm characteristics

Panel A	No energy constraint		Energy constraint		t-test (P-value)
Variable	Obs	Mean	Obs	Mean	
GVC	35,906	0.13	18,343	0.10	0.00
Panel B	**Low productivity**		**High productivity**		**t-test (P-value)**
Variable	Obs	Mean	Obs	Mean	
GVC	27,545	0.11	26,704	0.13	0.00
Panel C	**Low machine purchase**		**High machine purchase**		**t-test (P-value)**
Variable	Obs	Mean	Obs	Mean	
GVC	28,231	0.06	26,018	0.19	0.00
Panel D	**Low energy cost**		**High energy cost**		**t-test (P-value)**
Variable	Obs	Mean	Obs	Mean	
GVC	27,569	0.06	25,810	0.19	0.00
Panel E	**SMEs**		**Large-sized firms**		**t-test (P-value)**
Variable	Obs	Mean	Obs	Mean	
GVC	41,153	0.07	13,096	0.28	0.00

3.2. Model specificAtion

We follow the current literature on the effects of energy constraints (Allcott et al., 2016; Abeberese, 2017) and determinants of GVC participation (Reddy et al., 2020; Reddy and Sasidharan, 2021) to specify the benchmark model as follows:

$$GVC_{ik} = \beta_0 + \beta_1 EC_{ik} + \beta_2 CONTROL_{ik} + \gamma_{ck} + \lambda_t + \varepsilon_{ik} \quad (1)$$

Where subscript *i*, *k*, and *c* refer to firm, sector, and country, respectively. γ_{ck} and λ_t stand for country-sector-fixed and year-fixed effects to control the unobserved country-sector-specific and macroeconomic determinants, respectively. GVC_{ik} is the GVC participation decision of firm *i* in sector *k*. $Energy_{ik}$ is an energy constraint variable. $CONTROL_{ik}$ is a set of control variables. ε_{ik} has a normal distribution with a zero mean and unit variance. We report cluster standard errors at the sector-location level. Since GVC_{ik} is a dummy variable, it is standard practice to use the logit technique to estimate the probability of GVC participation. However, throughout the paper, we primarily employ the linear probability model, with the logit technique used as a robustness check. The main reason for this choice is that we utilize the method of mediating analysis alike Karahasan and Bilgel (2020) and Zhang et al. (2020), which is based on linear regression, to explore the pathways through which energy constraints affect firm participation in GVCs.

In the dataset, only 12% of firms have participated in GVCs. Specifically, out of 54,249 observations, approximately 6,510 firms have joined GVCs, while around 47,739 firms have not. This means that the dependent variable has about 7.3 times fewer instances of "GVC participation" compared to "non-GVC participation."

There are some concerns with model specification (1). First, a potential source of endogeneity includes reverse causality, as the observed outcomes might actually be determinants of a firm's

3. We divide firms into two groups: below and above the median of productivity, machine purchase, and energy cost, respectively.

Table 2: Statistical summary

Variables	Count	Mean	SD	Min	Max
GVC	54249	0.12	0.33	0.00	1.00
EC	54249	0.34	0.47	0.00	1.00
Sale	54249	13.64	2.54	8.65	20.26
Firm Age	54249	2.82	0.81	0.69	4.84
Firm Manager	54249	2.83	0.66	0.69	3.93
Digital	54249	0.69	0.46	0.00	1.00
Informal	54249	0.07	0.26	0.00	1.00
Innovation	54249	0.38	0.49	0.00	1.00
Foreigntech	54249	0.14	0.35	0.00	1.00
Foreign	54249	0.10	0.29	0.00	1.00
Fin Obstacle	54249	0.22	0.42	0.00	1.00
Mediators					
Productivity	54249	2.61	2.24	−11.05	10.23
Energy cost	53379	0.99	1.56	0.00	13.27
Machine value	54249	0.19	0.62	0.00	8.52

energy constraint. Another issue is omitted variable bias, where there may be unmeasured variables related to GVC participation that also affect a firm's energy constraint. The third source of bias in our analysis arises from the correlation among independent variables, due to the "self-selection effects" of firms. Firms with lower productivity or poorer financial access are more likely to experience energy constraints. As a result, there may be a correlation or even a causal relationship between independent variables like energy constraints, productivity, and financial access. These interdependencies or causal links among the independent variables could lead to biased estimates.

To address this potential bias, we employ the Entropy Balancing (EB) technique introduced by Hainmueller (2012)[4]. This method adjusts the weights assigned to observations based on the treatment factor (such as GVC participation status) to achieve balance across all relevant covariates. Essentially, it extends the traditional practice of weighting observations based on propensity scores. The calculation of the projected counterfactual mean includes:

$$E\left[\widehat{GVC(0)|EC=1}\right] = \frac{\sum_{i|EC=0} GVC_i EC_i^{EB}}{\sum_{i|EC=0} EC_i^{EB}} \tag{2}$$

In this approach, the weight assigned to each reference unit, denoted as EC_i^{EB}, is determined by minimizing a loss function. This function measures the difference between the distribution of control weights obtained and the original baseline weights. The minimization process involves adhering to various constraints, including balance constraints, which depend on the researcher's preferences. While the method shows theoretical promise, it may face challenges in accurately assigning weights if the balance constraints are not appropriately chosen.

Moreover, in our method, we achieve equilibrium between the two sets using the same covariates applied in the one-to-one matching process. However, it is important to note that year-specific and sector-specific factors are not accounted for in this context. The results presented in Table 3 show that all covariates in both the treated and control groups have statistically insignificant differences in means. This indicates that entropy balancing effectively achieves balance between these two groups.

Based on the concept of entropy balancing, our model can be represented as follows:

$$GVC_i = \beta_0 + \beta_1 EC_i^{EB} + \beta_2 CONTROL_i + \gamma_{ck} + \lambda_t + \varepsilon_i \tag{3}$$

Where GVC_i^{EB} reflects the entropy balancing weight.

We initially examine the relationship between energy constraints and GVC participation without addressing endogeneity bias. Subsequently, we apply the EB approach to correct for the endogeneity effect. Additionally, we apply the mediating analysis to uncover the channels in which energy constraints affect GVC participation. Furthermore, we conduct heterogeneous analysis across year, firm size, sectors, and region. Finally, we assess the robustness of our findings by using alternative measures of GVC participation and energy constraint.

4. EMPIRICAL RESULTS

4.1. Benchmark Results

Table 4 describes the baseline results of our regression by using equation (1). It can be seen that energy constraint has a negative impact on GVC participation. In other words, energy constraint reduces the probability of firm's participation in GVC.

To address the issue of endogeneity, we employed the EB method. This approach enables us to obtain more reliable and unbiased coefficient estimates. As shown in Table 5, the results are consistent with those in Table 4. Specifically, experiencing energy constraints reduces the probability of GVC participation by 1%. This statistically significant negative correlation between energy constraints and GVC participation supports our hypothesis that energy constraints hinder GVC involvement. This finding is consistent with the theoretical framework discussed by Danaf et al. (2020), who emphasize that endogeneity in discrete choice models can lead to inconsistent parameter estimates unless the data generation process is properly accounted for. Furthermore, the importance of addressing unobserved confounding factors is underscored by Wang et al. (2023), who propose novel approaches for estimating causal hazard ratios in the presence of unmeasured confounders, thereby enhancing the causal interpretability of the results. The broader implications of these findings are significant, as they suggest that energy constraints could act as a barrier to economic activities that rely on GVCs, potentially affecting global economic dynamics. Therefore, our findings not only reinforce the negative impact of energy constraints on GVC participation but also underscore the importance of addressing endogeneity and unobserved confounders to obtain accurate and meaningful insights into economic and energy interactions.

We then examine the role of control variables. The firm's sale per worker is positively associated with GVC participation. For instance, an 1% increase in sale per worker leads to a probability of GVC participation by about 2%. This result is aligned with

4. Recently, Doan (2024) applied the same method to investigate the impact of GVC on firm failure, using the WBES dataset.

Table 3: Balancing test

	Panel A: Unmatched			Panel B: Balanced sample		
	Untreated	Treated	P-value	Untreated	Treated	P-value
Sale	13.63	13.62	0.16	13.62	13.62	0.99
Firm Age	2.84	2.77	0.00	2.77	2.77	0.99
Firm Manager	2.83	2.76	0.00	2.80	2.80	0.99
Digital	0.73	0.68	0.00	0.68	0.68	0.99
Informal	0.06	0.08	0.00	0.08	0.08	0.99
Innovation	0.39	0.42	0.00	0.42	0.42	0.99
Foreigntech	0.15	0.14	0.19	0.15	0.15	0.99
Foreign	0.09	0.11	0.00	0.10	0.10	0.99
FinObstacle	0.15	0.34	0.00	0.35	0.35	0.99

Table 4: Baseline result without endogeneity control

Variables	(1)
	GVC
EC	−0.01***
	(0.003)
Sale	0.02***
	(0.002)
FirmAge	0.04***
	(0.003)
FirmManager	−0.01***
	(0.003)
Digital	0.05***
	(0.005)
Informal	−0.02***
	(0.005)
Innovation	0.06***
	(0.004)
Foreigntech	0.10***
	(0.006)
Foreign	0.19***
	(0.009)
FinObstacle	−0.01***
	(0.004)
Constant	−0.56***
	(0.036)
Observations	54,249
R-squared	0.281
Cluster standard errors at a country-sector level	

***P<0.01, **P<0.05, *P<0.1

Table 5: Baseline result with endogeneity control

Variables	(1)
	GVC
EC^{EB}	−0.01***
	(0.003)
Sale	0.02***
	(0.002)
FirmAge	0.04***
	(0.003)
FirmManager	−0.01***
	(0.003)
Digital	0.05***
	(0.005)
Informal	−0.02***
	(0.005)
Innovation	0.05***
	(0.005)
Foreigntech	0.10***
	(0.007)
Foreign	0.18***
	(0.010)
FinObstacle	−0.01***
	(0.003)
Constant	−0.12**
	(0.048)
Observations	54,249
R-squared	0.268
Cluster standard errors at a country-sector level	

***P<0.01, **P<0.05, *P<0.1

The tables exhibits the estimation results using an EB method and lineary probability model. CONTROL variables include Sale, FirmAge, FirmManager, Digital, Informal, Innovation, Foreigntech, Foreign, and FinObstacle; We add country-sector and year-fixed effect

previous studies (Reddy et al., 2020; Reddy and Sasidharan, 2021). Likewise, the positive and statistically significant coefficient, FirmAge, suggests that mature firms have a high possibility of joining GVC as they may benefit from the process of gaining knowledge and suffering lower sunk costs over time (Minetti et al., 2019). Furthermore, we indicate that innovation captured by forming new products or processes, Innovation, is positively associated with GVC participation because the more innovative and technological capacity of firms enhances their ability to meet the restrictive global standards and efficient degree (Reddy et al., 2020). Digital transformation improves firm participation in GVC, that is aligned with Gopalan et al. (2022). Finally, foreign technology and foreign ownership spur GVC participation as foreign-owned firms find it easier to access resources, information, and technical expertise (Reddy et al., 2020).

By contrast, the measure of financial constraints shows a statistically negative significance in relation to firm GVC participation, as inferred by several economists (Reddy and Sasidharan, 2021). Similarly, the coefficient of a manager's past experience is negative and statistically significant, indicating that as a CEO's experience and skills increase, the firm's likelihood of engaging in GVC decreases. This phenomenon can be attributed to several factors. First, CEOs who transition directly from a previous CEO role or have job-specific experience in similar industries often lead to lower post-succession financial performance, suggesting that their skills may not be as transferable or beneficial in new contexts, thereby reducing the firm's competitive edge in global markets (Hamori and Koyuncu, 2015). Furthermore, the intensity of a CEO's early-life exposure to fatal disasters influences their risk-taking behavior, with those experiencing less severe consequences tending to adopt more aggressive corporate policies, while those witnessing extreme downsides behave more conservatively, potentially limiting the firm's international expansion efforts (Bernile et al., 2017).

In addition, firms that start operating in the informal sector but then turn into the formal sector, Informal, are less likely to participate in GVC than those that are founded with registered businesses. Our result is consistent with Colovic et al. (2022), that documented that firms that started out as informal tend to experience the liability of informality since primary exposure to a weak institutional environment firmly and enduringly imprints the structures firms grow. In addition, primary exposure to scarce resources leads to a long-term liability that is hard to defeat as it is rooted in the growing structure of young firms.

4.2. Mechanism Analysis

In this section, we employed a mediating effects model to pinpoint the specific mechanisms of energy constraint. We adopt the method of mechanism analysis (Karahasan and Bilgel, 2020; Zhang et al., 2020) to construct the following model, using *M* as the mediating variable:

$$GVC_i = \gamma_0 + \gamma_1 M_i + \gamma_2 CONTROL_i + \gamma_{ck} + \lambda_t + \varepsilon_{it} \quad (4)$$

$$M_i = \lambda_0 + \lambda_1 EC_i + \lambda_2 CONTROL_i + \gamma_{ck} + \lambda_t + \varepsilon_{it} \quad (5)$$

Furthermore, the regression model, structured with *M* as the mediating variable, is:

$$GVC_i = \eta_0 + \eta_1 EC_i + \eta_2 M_i + \eta_3 CONTROL_i + \gamma_{ck} + \lambda_t + \varepsilon_{it} \quad (6)$$

If energy constraints have both a direct effect on GVC participation and an indirect effect through a mediating variable—which in turn affects GVC participation, then the coefficients η_1 and η_2 in Equation (6) should be significant. The indirect effects of the mediating variable, while accounting for the direct effect of energy constraints on GVC participation, are represented by $\lambda_1 \eta_2$. If energy constraints impact GVC participation solely through the mediating variable, then η_1 will be insignificant and η_2 will be significant, indicating that the mediator fully mediates the relationship. If η_1 is significant but η_2 is not, then there are no mediating effects.

We use total factor productivity (*TFP*)[5], energy cost (*Energycost*), and machine purchase value (*Machinevalue*) to investigate the channels of productivity reduction, increased energy costs, and decreased spending on machinery, respectively. Columns (1), (4), and (7) show that these mediating variables significantly impact GVC participation. Additionally, as expected, columns (2), (5), and (8) of Table 6 demonstrate that firms experiencing energy constraints experience a significant 2% decrease in productivity, a 5% increase in energy costs, and a 3% reduction in the value of machine purchases.

Lastly, columns (3), (6), and (9) of Table 6 present the estimates of factors affecting GVC participation with the inclusion of each mediating variable. The results show that, when considering the mediating variables, the coefficient for energy constraints remains negative and significant, indicating that firms facing energy constraints experience a reduction in GVC participation by approximately 1-2%. Additionally, we find that a 1% increase in TFP, energy cost, and machine value increases the probability of GVC participation by 1%, 4%, and 4%, respectively. These results support our hypotheses H1, H2, and H3. These findings indicate that TFP, energy costs, and the value of machine purchases partially mediate the effect of energy constraints on GVC participation.

4.3. Heterogeneity Analysis

In this subsection, we delve into the factors that moderate the impact of energy constraints on GVC participation. Recognizing a potential structural break post-2015, we re-estimate Equation (3) using two sub-samples: 2005-2015 and 2016-2022. The results, presented in columns (1) and (2) of Panel A in Table 7, reveal that the effects of energy constraints have intensified in the post-2015 period compared to the earlier timeframe. In the context of energy markets, the study on oil and gas prices demonstrated that structural breaks could influence long-term properties and mean-reverting behavior, suggesting that external factors beyond supply and demand play a critical role in price dynamics. Therefore, the intensified effects of energy constraints post-2015 likely reflect broader structural changes in the global energy landscape, influenced by geopolitical events, policy shifts, and market dynamics.

Additionally, we consider the role of firm size, with columns (3) and (4) indicating that small and medium-sized enterprises (SMEs) are disproportionately affected by energy constraints.

5. We use the TFP alike Aga and Francis (2017) and Francis et al. (2020). Data of TFP is obtained from WBES.

Table 6: Mechanism analysis

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Productivity reduction			Energy cost			Machine purchase		
	GVC	TFP	GVC	GVC	Energycost	GVC	GVC	Machinevalue	GVC
M	0.01***		0.01***	0.04***		0.04***	0.04***		0.04***
	(0.004)		(0.004)	(0.003)		(0.003)	(0.005)		(0.005)
EC		−0.02**	−0.02***		0.05***	−0.01***		−0.03***	−0.02***
		(0.009)	(0.004)		(0.013)	(0.003)		(0.010)	(0.004)
Constant	0.13**	−9.84***	0.13***	−0.39***	−4.79***	−0.39***	0.05	−1.54***	0.05
	(0.051)	(0.101)	(0.051)	(0.035)	(0.237)	(0.035)	(0.037)	(0.122)	(0.037)
Observations	54,249	54,249	54,249	53,379	53,379	53,379	54,249	54,249	54,249
R-squared	0.188	0.923	0.188	0.289	0.688	0.289	0.191	0.320	0.191
Cluster standard errors at a country-sector level									

***P<0.01, **P<0.05, *P<0.1

A full set of variables, CONTROL, is included in regressions

Table 7: Heterogeneity analysis

Panel A: Estimation results with subsample by year, firm size, and sector						
Variables	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
	By year		**Firm size**		**Energy-intensive sectors**	
	2005-2015	**2016-2022**	**SMEs**	**Large-size firms**	**Non-energy-intensive**	**Energy-intensive**
EC^{EB}	−0.02***	−0.04***	−0.02***	−0.02	−0.02***	−0.03***
	(0.006)	(0.011)	(0.005)	(0.016)	(0.006)	(0.010)
Constant	−0.12***	−0.13**	−0.03	−0.29***	−0.07**	−0.05
	(0.026)	(0.061)	(0.027)	(0.079)	(0.028)	(0.049)
Observations	31,719	22,530	41,153	13,096	29,279	24,970
R-squared	0.139	0.230	0.142	0.211	0.126	0.223
Panel B: Estimation results with subsample by region						
Variables	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
	EAP	**ECA**	**LAC**	**MENA**	**SA**	**SSA**
EC^{EB}	−0.00	−0.06***	−0.03**	0.00	−0.02	0.01
	(0.018)	(0.016)	(0.012)	(0.008)	(0.011)	(0.005)
Constant	−0.05	−0.20**	0.12	−0.12**	−0.21***	−0.14***
	(0.064)	(0.085)	(0.079)	(0.056)	(0.067)	(0.050)
Observations	6,657	12,203	11,113	6,673	10,134	7,469
R-squared	0.226	0.226	0.181	0.179	0.066	0.138
Cluster standard errors at a country-sector level						

***P<0.01, **P<0.05, *P<0.1

A full set of variables, CONTROL, is included in regressions

EAP is East Asia and Pacific; ECA is Europe and Central Asia; LAC is Latin America and Caribbean; MENA is Middle East and North Africa; SA is South Asia; SSA is Sub-Saharan Africa

This is likely because GVC participation demands reliable energy use, which energy-constrained SMEs struggle to secure. This observation is consistent with the higher energy intensity of production in transition economies, where inefficient energy use can hinder economic growth and GVC participation (Suslov, 2008). Furthermore, we examine whether firms operate in energy-intensive sectors, following De Bruyn et al. (2020) to define energy-intensive sectors that include paper and pulp, inorganic chemicals, petrochemicals, fertilizer, glass, cement, lime and plaster, and aluminum.[6] The regression results for these sub-samples, shown in columns (5) and (6) of Panel A, indicate that the adverse effects of energy constraints are more pronounced in energy-intensive sectors. This is corroborated by findings that local governments' energy-saving target constraints can inhibit firm financialization, thereby affecting investment in energy efficiency and technological innovation, which are crucial for firms in energy-intensive industries to maintain competitiveness and participate in GVCs (Hu et al., 2023).

Next, as the relationship between energy constraint and GVC participation may change across regions, we re-regress Equation (3) based on the sub-sample by regions. Panel B of Table 7 indicates that such a relationship exists in ECA and LAC only, and such an adverse effect becomes more obvious in ECA. This finding aligns with the broader literature on energy intensity and economic growth, which shows that regions with higher energy intensity, such as many post-socialist countries, face significant challenges in improving energy efficiency and thus may experience more pronounced adverse effects on GVC participation (Suslov, 2008). Additionally, the impact of energy constraints on GVC participation can be linked to the varying levels of sustainable energy use across different regions. For instance, in E7 countries, sustainable energy use positively affects economic growth only if it exceeds a specific threshold, suggesting that regions with lower sustainable energy use may struggle more with energy constraints (Saqib, 2022). Finally, the role of embodied carbon in fossil energy trade and its varying effects across different GVCs suggests that high-income countries may benefit more from GVC participation in terms of environmental effects, while middle-income countries may not, further emphasizing the regional disparities in the impact of energy constraints on GVC participation (Zheng et al., 2024).

4.4. Robustness Check

In this part, we investigate the robustness of our results by using alternative measures of energy constraints and GVC participation. We also use a wider measure of GVC status (*GVC_Alter*) that receive a value of 1 if a firm is a two-way trader and 0 otherwise. Column (1) of Table 8 indicates that the impact of *GVC_Alter* is associated with that of the benchmark measure in Table 3 in terms of the sign and the degree of significance.

Next, so far, we use a subjective measure of energy constraint. In this part, we construct objective measures based on the natural logarithm of number of power outages (*NumPowerOut*) and the ratio of loss caused by power outages to total sales (*LossPowerOut*). While the former captures the intensity of power outages, the latter reflects the actual costs. Results reported in columns (2) and (3) show that our main results are robust in terms of sign and the level of statistical significance, thereby providing a more precise and quantifiable understanding of the economic burden imposed by power outages on firms. Our findings align with various studies that highlight the significant costs associated with power outages. For instance, research on African firms indicates that unmitigated costs of power outages remain substantial despite widespread investment in backup generators, with costs ranging between 1.25 per kWh of unsupplied electricity (Oseni et al., 2013). Similarly, a study on the

6. We use ISIC code Version 3.1: 20 – 29, 35, and 36.

Table 8: Estimation results with alternative measures

Variables	(1)	(2)	(3)
	GVC_Alter	GVC	GVC
EC^{EB}	−0.01**		
	(0.006)		
NumPowerOut		−0.01***	
		(0.003)	
LossPowerOut			−0.08***
			(0.017)
Salecap	0.02***	0.00***	0.00**
	(0.002)	(0.001)	(0.001)
FirmAge	0.04***	0.04***	0.04***
	(0.003)	(0.003)	(0.004)
FirmManager	0.00	−0.00	−0.00
	(0.003)	(0.004)	(0.004)
Digital	0.10***	0.07***	0.07***
	(0.008)	(0.006)	(0.006)
Informal	−0.02***	−0.04***	−0.03***
	(0.008)	(0.006)	(0.007)
Innovation	0.09***	0.05***	0.05***
	(0.006)	(0.006)	(0.007)
Foreigntech	0.11***	0.10***	0.11***
	(0.007)	(0.009)	(0.011)
Foreign	0.27***	0.18***	0.15***
	(0.010)	(0.012)	(0.014)
FinObstacle	−0.01	−0.02***	−0.02***
	(0.005)	(0.005)	(0.005)
Constant	0.24***	−0.01	−0.02
	(0.046)	(0.047)	(0.062)
Observations	54,249	25,909	17,353
R-squared	0.351	0.173	0.161
Cluster standard errors at a country-sector level			

***P<0.01, **P<0.05, *P<0.1

Due to the missing data of NumPowerOut and LossPowerOut, the number of observations significantly shrink in columns (2) and (3)

Table 9: Estimation result with IV

Variables	(1)
	GVC
EC^{IV}	−0.02***
	(0.005)
Sale	−0.00***
	(0.001)
FirmAge	0.05***
	(0.002)
FirmManager	0.01***
	(0.002)
Digital	0.08***
	(0.002)
Informal	−0.05***
	(0.004)
Innovation	0.07***
	(0.003)
Foreigntech	0.11***
	(0.005)
Foreign	0.23***
	(0.007)
FinObstacle	−0.02***
	(0.003)
Constant	−0.13***
	(0.010)
Observations	54,249
R-squared	0.143
Robust standard errors in parentheses	

***P<0.01, **P<0.05, *P<0.1

Result of second-stage IV estimation is reported

Swedish industrial sector reveals that the cost of a 1-h outage can be up to 120 times the market value of the undelivered electricity, particularly in high electricity intensity sectors like the electro and motor vehicle industries (Broberg et al., 2021).

To ensure the robustness of our results, we also used the logit technique in addition to the LPM. The estimation results of equation (3) using the logit model are consistent with our benchmark findings.[7]

Lastly, to fix the endogeneity problem, we use Fisman and Love' (2003) sector-location average approach to compute an instrument variable. Particularly, we divide the energy constraint induced by firm *i* in the *k*-th sector (Ec_{ik}) into two components:

$$Ec_{ik} = EC_{ik} + EC_k \quad (7)$$

Where EC_{ik} remits an idiosyncratic element and EC_k is the average value of energy constraint that is the same for all firms operating in the *k*-th sector. The main assumption is that the sector average energy constraint is not correlated to the firms' GVC decisions. In the next step, we use the sector average of the energy constraint variable as our instrument. Hence, with the instrumental variable approach, our model can be given as follows:

$$GVC_i = \beta_0 + \beta_1 EC_i^{IV} + \beta_2 CONTROL_i + \gamma_{ck} + \lambda_t + \varepsilon_i \quad (8)$$

Where EC_i^{IV} represents the fitted value obtained from the first-step regression, where we regressed energy constraint on the average GVC participation at the country-sector level along with a set of control variables. We conducted several endogeneity tests to assess the validity of our proposed instrumental variables. The estimation results of equation (8) reported in Table 9 are consistent with our baseline findings.

5. CONCLUSION AND POLICY IMPLICATIONS

This paper provides a comprehensive analysis of the effects of energy constraints on firms' participation in GVCs. Using data from 54,249 observations across 119 countries from 2005 to 2022, our findings demonstrate that firms facing more severe energy constraints experience greater difficulty in participating in GVCs. These adverse effects are primarily transmitted through reduced productivity, increased energy costs, and decreased capital investment in machinery. The impact of energy constraints on GVC participation is not uniform, varying across different years, firm sizes, sectors, and regions. Additionally, our results remain robust across various measures and controls for endogeneity.

The findings from this study suggest several important policy implications. First governments should prioritize improving energy infrastructure to ensure a stable and reliable supply of electricity. This is particularly crucial for developing countries where energy

7. This result is available from the corresponding author upon reasonable request.

constraints are more pronounced. Investments in renewable energy sources and modernizing the energy grid can help reduce energy costs and enhance reliability. Second, policymakers should provide incentives for firms to adopt energy-efficient technologies and practices. This could include tax breaks, subsidies, or grants for investments in energy-saving equipment. By reducing energy costs, firms can improve their competitiveness and increase their participation in GVCs. Third, given that smaller firms are more vulnerable to energy constraints, targeted support for these firms is essential. This could involve providing easier access to financing for energy-efficient investments or offering technical assistance to help them optimize their energy use. Fourth, recognizing that the impact of energy constraints varies by sector, policymakers should develop sector-specific strategies to address these challenges. For example, energy-intensive industries may require different support measures compared to less energy-dependent sectors.

For managerial implications, the findings highlight the importance of addressing energy constraints as a strategic priority. Managers should consider investing in energy-efficient technologies and practices to reduce operational costs and enhance productivity. This includes exploring alternative energy sources and improving energy management systems. Also, firms should incorporate energy risk assessments into their strategic planning processes. This involves identifying potential energy supply disruptions and developing contingency plans to mitigate these risks. Managers should take advantage of government programs and incentives aimed at promoting energy efficiency and reducing costs. Staying informed about available support can help firms make informed decisions about energy investments. Emphasizing long-term sustainability can provide a competitive advantage. Firms that proactively manage their energy use and invest in sustainable practices are better positioned to navigate the challenges of global markets and enhance their participation in GVCs.

In spite of several robustness checks, our study still has some limitations. The role of process trading in the global production chain is growing. In this domain, it is vital to quantify the effect of energy constraints between firms with ordinary trade and that with processing trade. Nevertheless, the data limitation prevents us from conducting such an analysis.

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APPENDIX

Table A1: List of countries

No.	Country	Percent	No.	Country	Percent	No.	Country	Percent
1	AFG	0.08	41	GTM	1	81	NLD	0.5
2	AGO	0.38	42	HND	0.56	82	NPL	0.95
3	ALB	0.16	43	HRV	0.71	83	PAK	1.73
4	ARG	1.91	44	HUN	0.8	84	PAN	0.26
5	ARM	0.32	45	IDN	2.45	85	PER	2.44
6	AUT	0.32	46	IND	13.21	86	PHL	1.05
7	AZE	0.15	47	IRL	0.25	87	POL	0.42
8	BDI	0.23	48	IRQ	1.06	88	PRT	0.94
9	BEL	0.34	49	ISR	0.2	89	PRY	0.39
10	BEN	0.08	50	ITA	0.47	90	PSE	0.55
11	BGD	2.63	51	JAM	0.16	91	ROU	0.85
12	BGR	1.18	52	JOR	0.38	92	RUS	1.9
13	BIH	0.27	53	KAZ	0.91	93	RWA	0.29
14	BLR	0.57	54	KEN	1.56	94	SAU	0.9
15	BOL	0.5	55	KGZ	0.34	95	SEN	0.59
16	BRA	1.79	56	KHM	0.56	96	SGP	0.16
17	BRB	0.05	57	LBN	0.58	97	SLB	0.05
18	BTN	0.08	58	LBR	0.11	98	SLE	0.26
19	BWA	0.27	59	LSO	0.11	99	SRB	0.35
20	CHL	1.86	60	LTU	0.3	100	SUR	0.04
21	CHN	2.25	61	LUX	0.02	101	SVK	0.4
22	CMR	0.19	62	LVA	0.22	102	SVN	0.41
23	COL	2.69	63	MAR	0.61	103	SWE	0.89
24	CRI	0.38	64	MDA	0.25	104	TCD	0.22
25	CYP	0.06	65	MDG	0.43	105	TGO	0.03
26	DEU	0.86	66	MEX	4.33	106	THA	0.92
27	DNK	0.62	67	MLI	0.62	107	TJK	0.16
28	ECU	0.77	68	MLT	0.11	108	TLS	0.13
29	EGY	7.15	69	MMR	0.82	109	TUN	0.56
30	ESP	1.04	70	MNE	0.12	110	TZA	0.89
31	EST	0.3	71	MNG	0.46	111	UGA	0.67
32	ETH	0.49	72	MOZ	0.92	112	UKR	1.24
33	FIN	0.7	73	MRT	0.16	113	URY	0.63
34	FRA	1.21	74	MUS	0.18	114	UZB	0.88
35	GEO	0.54	75	MWI	0.05	115	VEN	0.04
36	GHA	0.8	76	MYS	1.29	116	VNM	2.12
37	GIN	0.24	77	NAM	0.18	117	YEM	0.2
38	GMB	0.25	78	NER	0	118	ZMB	1.02
39	GNB	0.08	79	NGA	2.07	119	ZWE	0.41
40	GRC	0.55	80	NIC	0.68			